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HELMET MOUNTED DISPLAY SYMBOLOGY FOR HELICOPTER LANDING ON SMALL SHIPS

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SUMMARY

Helmet Mounted Display symbology has been designed to aid in landing a specific helicopter, the SH-2F, on small ships, utilizing the NAVTOLAND Precision Landing Guidance System. A "maximal" display for single-pilot operation and a "minimal" display for two-pilot operation have been developed, both without head tracking. The "maximal" display provides all the necessary flight information in three modes for localizer acquisition, approach, and hover. Novel symbology is introduced for aiding the pilot in localizer acquisition under high wind conditions and for glide slope and localizer tracking during approach. The "minimal" display symbology relies on active participation by the co-pilot via verbal communication. In this display the presentation of the positioning information is based on the doppler Direction Velocity Indicator panel instrument format throughout approach and hover.

INTRODUCTION

The Navy has undertaken an integrated program for the development of V/STOL (rotary and fixed wing) hover and landing capability under adverse conditions. Criteria under consideration include operations in obscure ceiling/700-foot visibility and through sea state 5, on both aviation and non-aviation ships (Figure 1).

The Navy Vertical Takeoff and Landing (NAVTOLAND) program is addressing all elements of the V/STOL shipboard landing problem, including the Precision Landing Guidance System (PLGS), aircraft flight controls and cockpit displays, Visual Landing Aids (VLA) and piloting techniques. For manual approach and landing in adverse weather, effective integration of cockpit displays with aircraft control characteristics is required. Status information must be matched to the piloting task, and command information must account for the aircraft flying qualities as augmented by the electronic flight control system.

Display media must also be appropriate for the task and compatible for installation in a particular airframe. The Head-Up Display (HUD) and head down Multi-Purpose Display (MPD) in fixed wing V/STOL (AV-8B) provide adequate display media for Instrument Meteorological Condition (IMC) approach, and to some degree for final hover and landing as well. Representative reviews on this subject are References [1] through [11].

The head-down instruments found in helicopters, however, require strict crew coordination procedures for IMC approach and pose problems for effective transition to head-up flight after breakout, especially with reduced weather minima. Head-up displays are typically found only in attack helicopters and provide a limited field-of-view.

In recent years, the helicopter community has effectively pursued use of Helmet Mounted Displays (HMD) for target designation and for enhanced low visibility, low altitude operations. Visual augmentation using infrared (IR) or low light level sensors combined with artificial symbology has been investigated (References [12] through [16]).

It is appropriate then to consider the potential of an HMD for the shipboard IMC approach and landing task. In this role, the HMD is envisioned as a medium to display symbology only, since unaided visual contact with the ship is possible during the final phase of the approach even in the weather conditions under consideration. Furthermore, utilization of an HMD without head position tracking would simplify aircraft installation.

There are undoubtedly numerous human factor questions raised by such an implementation (e.g., disorientation). In order to begin addressing these questions, two candidate display formats for an HMD without head tracker have been developed for use in an SH-2F helicopter. Since the HMD is to be used only for the approach and landing task, the Helmet Display Unit (HDU) of the Honeywell Integrated Helmet and Display Sight System (IHADSS) has been selected as the baseline hardware set (Figure 2). The HDU clips onto the pilot's helmet and thus alleviates the need of carrying the extra HDU weight (12 oz) throughout the mission.

The goal of the Helmet Mounted Display symbology design presented here is to aid the pilot in performing landings on small non-aviation ships by means of utilizing the information available from the NAVTOLAND Precision Landing Guidance System and from other airborne sensors. The following constraints are significant:

(a) The specific helicopter to be considered is the SH-2F with its present Automatic Stability Equipment (ASE) and the instrument panel left unchanged

(b) No head tracker is to be used

(c) Extra training and proficiency flying required for the display is to be as little as possible.

Constraint (b) implies that the display should not be of the contact analog ("forward looking") type. The concept employed can be called a "helmet mounted instrument panel," enabling the pilot to avoid confusing overlapping of symbols and certain elements, like light sources, in the view of the ship. This combination of symbology and outside view is similar to helmet-fixed symbology superimposed on an IR display where the orientation of the swivelling IR sensor is governed by the pilot's head movements. Such a system is being flown successfully in the Surrogate Trainer for the U.S. Army Advanced Attack Helicopter.

Constraints (c) and (a) dictate a design philosophy that strongly utilizes the present training and experience of SH-2F pilots with the existing flight control system and cockpit instruments.

Two solutions, different in format and in content, have been synthesized and are presented here. A "maximal" display, intended for single-pilot operation, has three different modes, from localizer acquisition to hover, utilizing a moving-map type horizontal format throughout and introducing novel vertical display symbology derived from visual and instrument information used today.

A "minimal" display is synthesized based on the assumption that the co-pilot actively participates in the approach by providing the pilot with monitoring information verbally. This display utilizes essentially a single format throughout the approach, using error and error rate symbology derived from the Direction Velocity Indicator (DVI) panel instrument, with true situation shown only near hover.

The following principles were formulated as guidelines for the detailed design:

1. The information displayed on the HMD should eliminate the need to look inside the cockpit, except in response to warning.

2. Motions of display elements should not be in conflict with any panel display of similar information, especially insofar as evoked control modes are concerned.

3. The symbology chosen for various display modes should be "natural" in order to minimize the time and effort needed for familiarization and training.

4. Digital display of information may be used for monitoring purposes but not for continuous control loop closures.

In the following, the proposed display symbology is described in detail, including the reasoning for the choices of its various elements and features. The availability of a stroke-writing symbol generator is assumed.

A "MAXIMAL" DISPLAY FOR SINGLE-PILOT OPERATION

The Basic Display Format

The format common to all display modes of the "maximal" display involves elements of flight information that are available on the basic instrument panel. The central area of the display is to be reserved for various modes conveying positioning information, from localizer acquisition to hover. Because no head tracker is to be used, any resemblance between symbol movements and relative movements of outside objects should generally be avoided.

Display Principles 1., 2. and 4. govern the design of the basic display format. In order to minimize the difficulty of transitioning from cockpit instruments to the HMD symbology, as much information as possible is arranged resembling the instrument panel (Figure 3) so that the basic scanning pattern is not very different. Therefore, much of the important instrument information is arranged at the bottom of the display area. The center piece in this area is the sketch of the attitude gyro, with bank angle indicator, turn needle and side slip ball. Several of the instruments indicated in Figure 3 are not represented in the basic HMD format; some, because they convey information that is to be included in the appropriate display mode in the central area, others, because they are not considered primary information for the flight phases at hand. Automatic warnings must be flashed on the display when instruments not shown on the HMD indicate trouble (Figure 4).

In addition to the gyro display the following information is shown in the bottom area: radar altitude, barometric altitude, ground speed, air speed, percent rpm and percent torque. Given the use of the ASE, all of these indications are only to be monitored while positioning of the helicopter is to be performed based on the central-area information. For this reason it is proposed that these instrument readings be shown in digital form. The arrangement shown in Figure 4 resembles closely the relative locations of the respective instruments on the panel in relation to the gyro. Exceptions are that the rpm information is moved to the left of the air speed read-out so that it does not intrude into the central area, and that the ground speed is shown below the airspeed, in place of the bearing-distance-heading indicator. The moving heading scale is across the top of the display area. A rate-of-climb scale is shown on the left-hand side of the central area. An area on the right hand side is reserved for warning information.

In order to minimize the chances of disorientation, it is important that the pilot be aware of his head angle with respect to the airframe at all times. The fixed elements on the HMD provide a "frame" which can be related to cockpit features (e.g., instruments, windshield frame).

In the following sections, central-area display modes for localizer acquisition, approach and hover are described.

Localizer Acquisition (LA)

In the sequence of flight phases during approach and landing, the purpose of the first display mode is to aid the pilot in localizer acquisition. In high sea states the mean wind velocity is likely to be high which complicates the prediction of the flight path in a turn. This is considered the dominant problem in this flight phase.

The display needed for enhancing localizer acquisition is essentially a navigation mode with nominal approach path information to be added. Only a horizontal display is needed in the central area because this maneuver is performed at an altitude which can be held adequately by the ASE, or by the pilot using the altimeter and rate of climb information available on the display.

The scaling of the horizontal display in the LA mode is determined so that no scale change should be necessary during several minutes before localizer acquisition is completed. Assuming an air speed of 80 knots during this flight phase as the design point, a range of 3 miles allows seeing ahead for more than two minutes and gives adequate lateral range for a standard turn diameter.

The first significant element in this display mode is the presentation of the nominal approach path when the helicopter's relative location (range and azimuth) with respect to the ship and the nominal approach angle are known. In addition to the nominal approach line the following information is considered quite useful for the horizontal situation display: the orientation of the ship with respect to the approach path and its direction of travel, and the point on the approach path where tip-over should be performed assuming that the helicopter stays at the same altitude. The ship can be shown as a small symbol or as an arrow at the end of the approach line (Figure 5). If the ship itself is off scale then it should appear where the approach line terminates, with a gap between the line and the ship symbol; the gap is to disappear when the ship is within range and then the ship symbol appears attached to the end of the approach line.

In order to assist the pilot in planning his turn onto the approach path, two dotted antennae-like symbols emanate from the aircraft symbol. These lines represent the ground tracks for left and right nominal turning flight paths. In the simplest case, with no wind, these paths are half circles which are calculated based on the helicopter ground speed and the predetermined turn rate for a 2-minute 360° turn. For cross-checking purposes, and also in the case of inoperative automatic turn coordination, the needle-ball presentation at the bottom of the gyro can be used. Ideally, a turn should be flown in such a fashion that the nominal approach line becomes tangential to the nominal turn path when localizer acquisition is completed. Only constant-heading-rate turns are considered here.

Automatic turn coordination (zero side force) has been ranked among the highest priorities for feedback augmentation of helicopters and it is assumed available under the flight conditions considered here. The sketch in Figure 6 indicates that a horizontal force component perpendicular to the helicopter x-axis has components both perpendicular to and along the flight path. The former causes the flight path to curve while the latter represents an accelerating or decelerating force component depending upon the direction of the turn. The implication is that longitudinal control must be applied by the pilot or by the ASE in order to maintain the airspeed. Changes in ground speed occur during a turn unless a significant effort is made to maintain it constant, but no good reason can be seen to make this a requirement. The kinematics of turning helicopter flight is analyzed in Reference [17]; a simplified approximation for level turns with constant airspeed, based on a quasi-stationary analysis, results in very simple on-line calculations to obtain the dotted "antennae"; each consecutive dot represents a 15 deg absolute heading increment. Figure 7 illustrates the changing shape of the antennae as the wind direction changes in the course of a turn. The accuracy

of the predicted turn path can be monitored easily throughout the turn and appropriate modifications of the turn rate can be made to compensate for approximations and instrumentation errors, or for inadequate turn rate tracking during part of the turn.

Two more features might be added to the LA display if unused computational capacity is available. The first addresses the problem of timing the turn initiation when the approach path is moving sideways because it is at an angle with respect to the ship's line of travel. If the ship's speed is known, then a straightforward calculation can predict where the approach path would be located when it came nearest a nominal turn initiated immediately (see the double line segments in Figures 5 and 7). Under ideal conditions the turn should be initiated when the predictor path element becomes a tangent of the turn path. This element then remains tangential to the turn path throughout the standard turn while its distance from the actual moving approach path decreases to zero by the time localizer acquisition is completed. In the absence of such a predictor symbol the pilot must perform the prediction.

The second feature that might be added at significantly greater expense in computational capacity would provide bank angle commands throughout the turn. At each point along the nominal path the bank angle needed to provide the required flight path curvature can be calculated. In view of the small bank angles and the rather lax accuracy requirements in localizer acquisiton, this feature is only mentioned but is not recommended.

The localizer acquisition takes place at an altitude and a distance from the ship where head-down flying is quite acceptable. Therefore, the information and symbology devised here is not tied uniquely to an HMD but could be shown instead on an available panel-mounted tactical or other CRT display.

Approach and Deceleration to Hover (AP)

Localizer acquisition can be considered accomplished when the helicopter is in approximately straight line flight, its flight path orientation is within only a few degrees from the nominal path, the helicopter is within localizer range, and the range to the ship is decreasing. Switching to the Approach Mode can be done by the pilot when he deems it appropriate, or automatically based on the criteria above which have been formulated so that mode switching does not occur during an excessive overshoot.

The various horizontal velocity components playing a role in approach path tracking are shown in Figure 8. The helicopter motion with respect to the nominal approach reference line is affected by the airspeed, the inherent side slip, the wind velocity and the ship velocity vectors. In the case of a stern approach the situation is simplified by the fact that the nominal approach reference line does not translate orthogonally to its direction.

In order to enhance the pilot's tracking task a velocity vector must be displayed. There are two alternatives available. The ground velocity vector along the ground track, in general, must be at an angle with the nominal approach line in order to stay on the nominal path. This angle can be

calculated as $\delta_{ha} = \sin^{-1}((V_s \sin \gamma_{sa})/V_{hg})$ where V_s and V_{hg} are the ship and helicopter velocities and γ_{sa} is the angle between the ship velocity vector and the nominal approach line. The nominal end point of the helicopter ground velocity vector can be calculated and shown on the display.

The other alternative, using the same information, is to display the helicopter ground velocity component as referenced to the nominal approach line. This is the alternative proposed for the approach mode because tracking the nominal approach line is then essentially the same in the case of $\gamma_{sa} \neq 0$ as when $\gamma_{sa} = 0$ (Figure 9). From the pilot's viewpoint, the effect of a laterally translating approach line is the same as that of an additional wind component orthogonal to a non-translating nominal path.

As the approach speed is decreased, appropriate heading changes must be made. An experienced pilot is likely to anticipate most of the required change. Throughout, it is assumed that the pilot is using the ASE and is flying longitudinal trim while the automatic turn coordination keeps the ball centered even if there is no banking. It appears desirable to have the ASE in altitude-hold in this phase of the approach. For the present discussion it is assumed that the initial altitude before tip-over is such that after this maneuver there is adequate flying time available to establish glide slope tracking before the decelerating phase begins.

As long as the altitude is held constant or is not yet a crucial flight variable, the horizontal display provides sufficient information. When the explicitly marked tip-over point is approximately one-half minute flying time away, a horizontal scale change is in order and glide-slope referenced vertical information must be made available. A presentation of ILS needles might be used for this purpose; this alternative has been rejected because the cross hair panel instrument above the gyro, the Direction Velocity Indicator, represents a horizontal display and therefore evokes a different control response.

In the search for a solution the following line of thought evolved. The dominant reason for using an HMD or a HUD is that the pilot wants to make visual contact with the ship as soon as he can. Therefore, it is considered desirable that the pertinent information during approach be presented in the central display area in an uncluttered way. Today's pilot training and experience is based on visual approaches, with valuable cues provided by a Fresnel lens system ("meat ball") or other vertical guidance and the "hockey stick" appearance of approach and drop line lights. The closer the symbology resembles conditions flown routinely the less extra training and additional proficiency flying is necessary. The symbology for the vertical plane information proposed below combines and enhances the cues available from the hockey stick and the meat ball.

Figure 10 shows sketches of three different views of a landing platform and, below them, the symbology derived from these views. The vertical information (above/below nominal path) is derived from the fact that a shallower/steeper than nominal view of the platform changes the aspect ratio of its visual image. This is purposely exaggerated in the Figure in order to enhance

the resolution along the vertical axis. The centers of the two circles represent the points where the drop line and the extended approach line intersect the deck surface. The reference line, not available in the outside world, is provided so that the top circle is halved when the helicopter is on the nominal glide slope. The circle radius represents an angular glide slope deviation and the nominal spacing of the two circles is such that they would coincide at zero degree. As the absolute glide path deviations indicated by the circles shrink with decreasing range, there is to be a change-over from the angular representation to a linear representation.

The upper half of this symbology is designed to make it resemble a Fresnel lens system. In other words, the reference lines can be thought of as stabilized datum lines for a meatball at the bottom of the extended center line. For vertical error rate information, an arrow is added to the upper circle, as indicated in the sketches in Figure 10. No special symbol for localizer error rate is added because that information is perceptible from the changing shape of the hockey stick and is shown explicitly by the approach velocity vector in the horizontal display.

The vertical plane symbology set is placed above the horizontal display area so that the ship symbol of the horizontal display and the vertical display symbology set move together at all times. This assures a rather natural relationship by seeing the vertical information "looking down" along the approach line. A composite sketch of a "snapshot" of the resulting approach display mode just before tip-over, with glideslope and localizer errors, is shown in Figure 11.

Throughout the approach mode a digital readout of the closing rate appears at the left of the stationary aircraft symbol where it is cross-checked easily with the airspeed (as long as that is reliable) and the ground-speed shown at the left of the gyro. When a sensor output is unreliable its read-out is to disappear. The digital read-out of the range to the ship is shown next to the ship symbol at all times.

The approach of the tip-over point is shown by a bug traveling along the nominal approach line, and it can also be perceived on the hockey stick display because the upper circle is moving more rapidly toward its reference lines as the helicopter approaches the nominal glide path. During and after tip-over, until deceleration begins, the primary information for approach path tracking can be obtained from the vertical plane symbology.

The next phase of the approach is the deceleration to hover, identified by some pilots as the most taxing part of the approach under adverse conditions at night. It must be assumed that under extreme conditions the ship is not yet visible when deceleration is to be initiated. Fortunately, with the NAVTOLAND PLGS, it is possible to give the pilot adequate position and error information if some simple kinematic relationships are utilized. The point along the approach path where deceleration is to be initiated can be determined easily based on the known initial closing rate if the nominal deceleration of the closing rate is assumed to be a straightforward function of range only. For the purpose of this paper, constant deceleration is used as reference.

It is proposed that the pilot have the option of selecting a deceleration of -.1g or -.05g. Under adverse weather conditions pilots may well opt for the slower deceleration if they have appropriate information on their display to set up the deceleration and to stay within acceptable tracking errors even before they have a direct view of the ship. The display feature described below is designed to provide significant help to this effect.

The U.S. Army Avionics Research and Development Activity has developed and simulator-tested a nonlinear scaling of the velocity vector in the final approach phase (Reference [18]). The essence of this idea is that keeping the tip of the properly scaled velocity vector on the desired landing spot as displayed in a horizontal plane results in a prescribed deceleration time history depending on the scaling of the velocity vector. For example, linear scaling results in an exponential decay of approach speed. It can be shown easily that quadratic scaling, i.e., making the approach velocity vector proportional to the square of the closing rate, would yield constant deceleration under idealized conditions. Such a feature is incorporated in the proposed display.

Depending on the preselected value of deceleration an automatic scale change is to occur at a range of 1,000 ft or 2,000 ft and at the same time the ship symbol changes to a properly oriented landing pad. In this final approach mode the magnitude of the approach velocity vector at any given initial closing rate is equal to the easily pre-calculated distance of the ship symbol from the point where deceleration is to begin. The transitioning from constant airspeed to deceleration occurs when the ship symbol reaches the vector tip; from that time on the pilot must keep the vector tip on the ship symbol while making appropriate collective adjustments based on the glide slope error information. The described feature allows the pilot significant freedom to modulate the idealized procedure. He may choose the location where he wants to come to a hover and he may choose to apply larger or smaller decelerations over parts of the final approach. Making the appropriate corrections in case the initiation of the deceleration occurred somewhat late is also straightforward. In order to improve the tracking accuracy a final scale change in the approach mode should occur at 500 ft range.

In order to assure a smooth transition to hover the approach mode of the display is to be terminated at 100 ft from the nominal landing spot and the display should switch automatically to the hover mode described in the next section.

Hover Mode

By the time the switching to the hover mode occurs, detailed features of the ship are in sight. It is an unresolved question whether, from this point on, artificial symbology or the moving image of the ship would be used by pilots in actual flight although, at least in principle, the stabilized and well defined position information on a display may make hovering and maneuvering near hover easier than flying based on the moving ship reference. The goal of devising a hover display mode is to provide the pilot with the best possible information so that he may use the symbology as a significant source of information.

The hover display symbology is shown in Figure 12. The stationary aircraft symbol is inscribed in a circle representing the rotor to scale in order to provide innate perception of the horizontal scaling factor. The ship landing area is represented by a rectangle, also to scale, shown at the proper bearing, with the proper orientation. The nominal touch-down point is marked by a circle. For a linear control law the velocity vector tip should be kept on the "target" as mentioned in the preceding section in connection with proportional vector scaling.

The scale on the left can be used both for vertical position error and for rate indication if the center reference point on the scale denotes the nominal hover height and zero rate of climb. The actual hover height is indicated by two symbols moving together on the two sides of the scale; they are shaped to suggest a pair of wheels.

For illustration, the bottom of the vertical scale in Figure 12 represents the deck if it were not moving at a nominal hover height of 50 ft. The small reference circle shown there together with the two associated reference lines can be moved to any desired nominal hover height. Significant realism can be added to the display if landing spot motion information is transmitted to the hovering helicopter. This information can be used to show deck displacements in heave and sway as well as the deck roll angle. This motion being confirmed continuously by the moving background outside may contribute significantly to the confidence in the information displayed via the symbology.

No matter how good and successful a hover display proves to be, a nagging question remains to be addressed: what if the display fails while hovering? Obviously the pilot must have the capability to land safely based on visual cues with the help of the Landing Signal Enlisted (LSE) personnel and VLA unless a divert option exists. This means that he must have the proficiency to perform such a landing. The implication is that if he uses the display regularly because it makes his task easier, he actually looses proficiency in hovering and landing visually. These last two phases have been singled out for the above question because the close vicinity of hard surfaces makes proficient and quick reaction mandatory while the preceding phases might be handled relatively easier by simply slowing down. The conclusion is that great emphasis should be placed on devising a satisfactory stabilized hover VLA and, if that can be accomplished, the pilot may prefer to fly the VLA, with the central display area vacant, after the 100-ft hover range has been reached.

A "MINIMAL" DISPLAY FOR TWO-PILOT OPERATION

The display modes described in the preceding sections have been intended for single-pilot operation so that all the needed information is shown including some redundancies for enhancement and crosschecking. It was considered essential to provide situation information at all times. A much reduced display can be devised if two-pilot operation is assumed.

The design of a "minimal" display is based on the principle that most of the monitoring and slowly varying information can be communicated verbally to the pilot by the co-pilot. The elimination of such information from the pilot's display results in a reduced scan and therefore allows him to focus his visual attention entirely on the immediate flying task. All the instrument readings on the left hand side of the gyro, except for torque, can be eliminated from the basic display. The two altimeters on the right hand side are replaced by a single altitude read-out elsewhere on the display.

The minimal display does not address the localizer acquisition problem. It is assumed that, flying at a safe altitude, the pilot can arrive within localizer range flying on the cockpit instruments, using the available navigation aids and the tactical display. The tactical display, with some modification, could be augmented to provide most of the Localizer Acquisition mode described earlier. Consequently, most of the basic format can be reduced to a somewhat sketchy representation of the gyro, with turn needle and ball (Figure 13). Because only relatively small bank angles are used during the approach, only "wings level" references and $\pm$ 10° marks are shown at the two sides of the horizon line; these symbols move up and down with the pitch ladder. This modification is preferred to a pointer on top (as on the panel instrument) because with the elongated horizon line it provides improved resolution. The heading scale is eliminated entirely.

Percent torque is shown at the left of the gyro. A scale format has been chosen because no other numerical information has been retained near the gyro on the minimal display. Only absolute position information is shown in the form of digital read-outs: altitude on the left and range on top of the display area. Rate of descent and range rate can be perceived from the "ticking" of the corresponding absolute values. The closing rate can be shown explicitly below the range, if this is found necessary or highly desirable in the course of simulation experiments. For the pilot's assurance, the co-pilot should call out various flight information, like descent rate and airspeed, from time to time.

The minimal nature of the display is the result of eliminating monitoring information from the basic display and much of the situation information in the central area of the "maximal" display, and of having a single mode for localizer tracking, glide slope acquisition and tracking, deceleration and hover (Figure 13). This is accomplished by using the DVI format and augmenting it with error information. The symbology has been chosen so that control responses learned and exercised with the DVI instrument are maintained and utilized over the entire approach speed range, down to landing. Vertical, lateral and longitudinal display elements and control are discussed separately below.

The vertical symbology on the left is similar to that in the hover mode of the maximal display, but the meaning of the scale is modified in order to cover the entire approach. The center of the scale denotes a point on the nominal path, traveling along with the helicopter so that the pair of wheels show the altitude deviation from nominal. The scale itself is an altitude error scale and an altitude error rate scale at the same time with the ranges of $\pm$ 5°, changing to $\pm$ 50 ft near the ship, and $\pm$ 500 ft/sec, respectively.

The symbols are made to behave in the following way as the approach progresses. While flying on localizer before glideslope acquisition the ASE altitude-hold mode should be on. Accordingly, both the altitude and altitude rate indications show deviations from level flight. There is a negative glide-slope deviation not shown to the pilot until this error reduces to -1 deg which occurs, assuming a 3 deg nominal glideslope, at 1.5 times the range of the tip-over point for the given flying altitude. At this point automatic switch-over to glideslope error presentation occurs. Some flashing may be used to call the pilot's attention to this occurrence. From this time on the altitude deviation symbol indicates the glideslope error which is negative initially, while positive error rate indication shows that the negative error is being reduced in level flight. Before the error reduces to zero the altitude-hold mode must be turned off. The pilot's goal is to reduce error and error rate to zero at the same time, using the collective, while the airspeed is held constant. The vertical error scale, being in degrees, becomes more sensitive as the approach progresses; the sensitivity remains constant after the range has been reached where the one-degree error cone intersects the ten-foot radius error cylinder. The numerical values cited above are subject to modifications based on future simulator tests.

Figure 13 illustrates the case where the nominal glideslope terminates at a 50-ft hover height over the deck mean. Actual height-to-deck information is shown by a rising deck symbol which at hover should come to rest between the two reference lines slightly below the vertical scale. The gap between these reference lines and the bottom of the scale is such that in calm water the altitude "wheels" indicate touch-down when the helicopter wheels make contact with the deck. If ship information is available, the deck symbol can indicate the rolling and heaving of the landing area.

The horizontal display has been developed based on the pair of needles on the DVI which is essentially a velocity command display in helicopter axes. The same symbology is augmented with a position error symbol in such a fashion that keeping the needle on the stationary double circle results in a satisfactory control law for making a correction. The cross hair components are driven by positon error and error rate so that with zero error rate the cross hair is on the "target." This way the "fly to" nature of the DVI instrument is maintained. For simplicity, the minimal display employs constant gains for the rate components so that an exponential approach to the "target" is made if the cross hair is kept perfectly on the reference circle. It is recognized easily that the cross hair in effect leads the target motion with the speed being proportional to the distance between the cross hair and the target. This known relationship enables the pilot to deviate from the exponential law in a controlled fashion. He can lead the target anywhere he wishes and can stop the helicopter's relative motion with respect to the target by simply placing the cross hair on the target.

Lateral directional control throughout the approach and hover can be divided into two sections depending on the ASE control mode used: coordinated turn and heading hold. In both modes lateral stick motions control essentially the force component along the helicopter y-axis. As long as the airspeed is held by the ASE, longitudinal motion is not controlled by the pilot and the target box representing nominal position moves only laterally representing the

localizer deviation proportional to the angle, changing to a linear scale as a one-degree error becomes less than a ten-foot error. When the airspeed is high enough to allow for turn coordination by the ASE, only lateral stick inputs are needed for localizer tracking. At such speeds the drift angle is not very large and localizer error correction can be made using very gentle turns controlling the rate of change of the error rate.

The time constant of a perfect correction, keeping the cross hair nulled at all times, is determined by the ratio of the error rate and error display gains. Ratios of three to five, corresponding to time constants of three to five seconds have been found satisfactory in the past. A ratio of five means that, e.g. a symbol displacement for a 2 ft/sec error rate is the same as that for an error of 10 ft. In practice, the noisiness of the rate information is usually the limiting factor on the display gain.

After deceleration has been initiated the same control policy can be used as long as ASE turn coordination is effective and keeps the side force zero. As the airspeed is decreasing a continuous heading change is needed, except in the very simplest case when all the velocity vectors involved are aligned. At low speeds the controlled task becomes more difficult because the pilot must use the pedals to keep the ball approximately centered. In summary, localizer tracking throughout most of the approach, with the ASE on, can be accomplished in a straightforward manner keeping the cross hair "nulled" by means of bank angle corrections only.

For x-axis control the horizontal bar of the cross hair is used essentially as a velocity command symbol like the corresponding needle of the DVI. While the ASE holds airspeed this bar can be used to indicate deviations from the set value. Deceleration can be commanded by this bar as follows. As discussed in connection with the Approach Mode of the maximal display, given the range to the ship and the closing rate, the range at which deceleration is to be initiated and the velocity profile for a given deceleration can be predetermined in a straightforward manner. The bar would remain nulled throughout the deceleration if the varying closing rate were always controlled to the value pre-calculated for the decreasing range. This can hardly be done perfectly, considering the lag between an attitude change and the corresponding speed change. The deviations of the bar are to be proportional to the closing rate deviations from the pre-calculated nominal profile. This raw error information may have to be augmented by lead information in order to reduce the work load during deceleration. In order to minimize the transient effects at the initiation of the deceleration, warning of the upcoming maneuver may be provided by flashing of the horizontal bar and only a gradual increase in deceleration should be commanded. In addition, the pilot knows the pitch attitude change needed for a given deceleration.

During most of the deceleration a longitudinal position error is not really meaningful. In the minimal display true longitudinal situation is shown in the central area only near hover. If the approach is flown correctly, both the target box and the cross hair are near the null circles at all times. At a range of 100 ft from the nominal hover point the box reference switches to the nominal hover point. At the instant of switching, the box jumps from the vicinity of the null circles to the nominal hover point in

helicopter axes, near the top of the display area, with the proper orientation, and enlarged to scale to indicate the size of the landing area. From this time on both cross hair components move with the same error and error rate gains, leading to an exponential final approach to the hover point if the cross hair remains centered. It should be noted that the ship is already in view well before the reference point switching to hover occurs so that the situation information can be verified instantly.

In summary, the minimal display for two-pilot operation described above employs symbology derived from the DVI panel instrument used as a hover aid. That symbology is augmented to provide localizer and glide slope errors throughout the approach and situation information in three dimensions near hover. The velocity command feature of the DVI format is used to command a predetermined deceleration profile.

A great deal of attention has been given to choose the arrangement, the various display modes and the symbols in such a way that any disorientation arising from the image of the moving ship behind the display be possibly eliminated. Nevertheless, exploratory simulator experiments may well lead to some modifications in both the "maximal" and the "minimal" displays, and final verification can come only from flight experiments because of the difficulty of duplicating in the simulator the details of actual ship lighting conditions.

An evaluation of the HMD is planned as part of a NAVTOLAND SH-2F simulation to be conducted at the NASA Ames Research Center in 1982. The moving base simulation facility to be used incorporates a wide field-of-view computer generated image system. Figure 14 shows the simulator and the actual field-of-view available from the right seat of an SH-2F. A calligraphic symbol generator will drive the Honeywell HMD. The existing SH-2F mechanical flight control and ASE will be simulated. The experimental task will be a decelerating IMC approach to breakout and subsequent landing aboard a DD-963 class destroyer.

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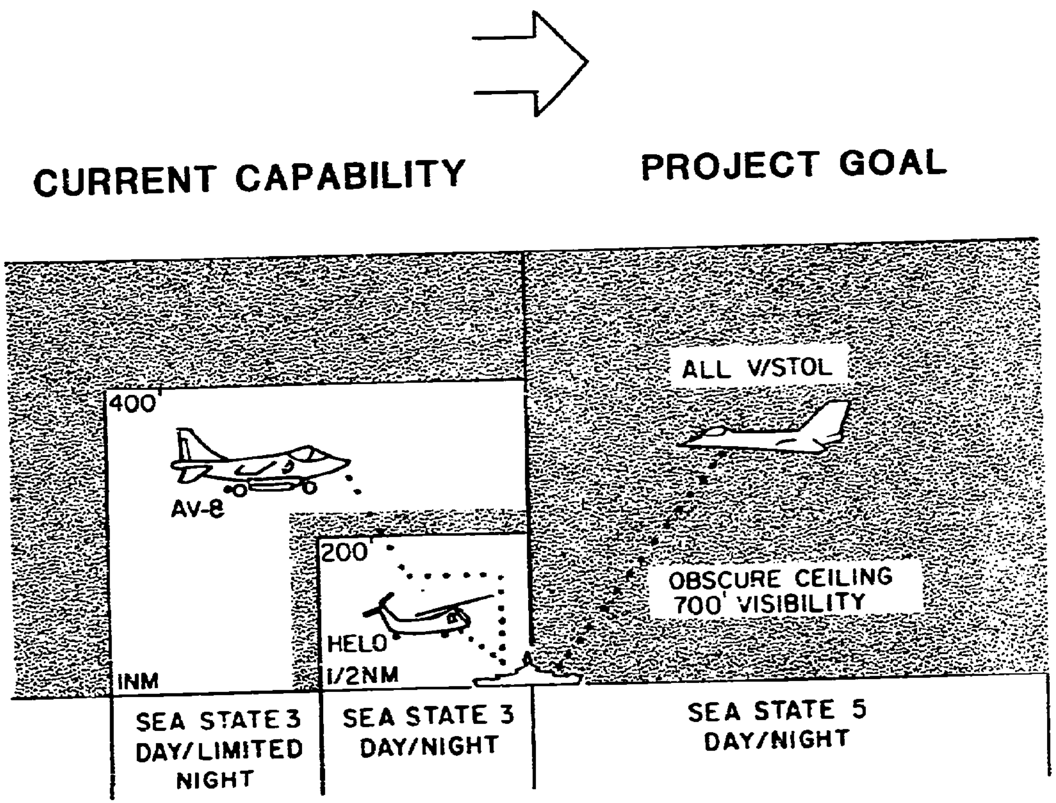

Figure 1. NAVTOLAND Project Goal.

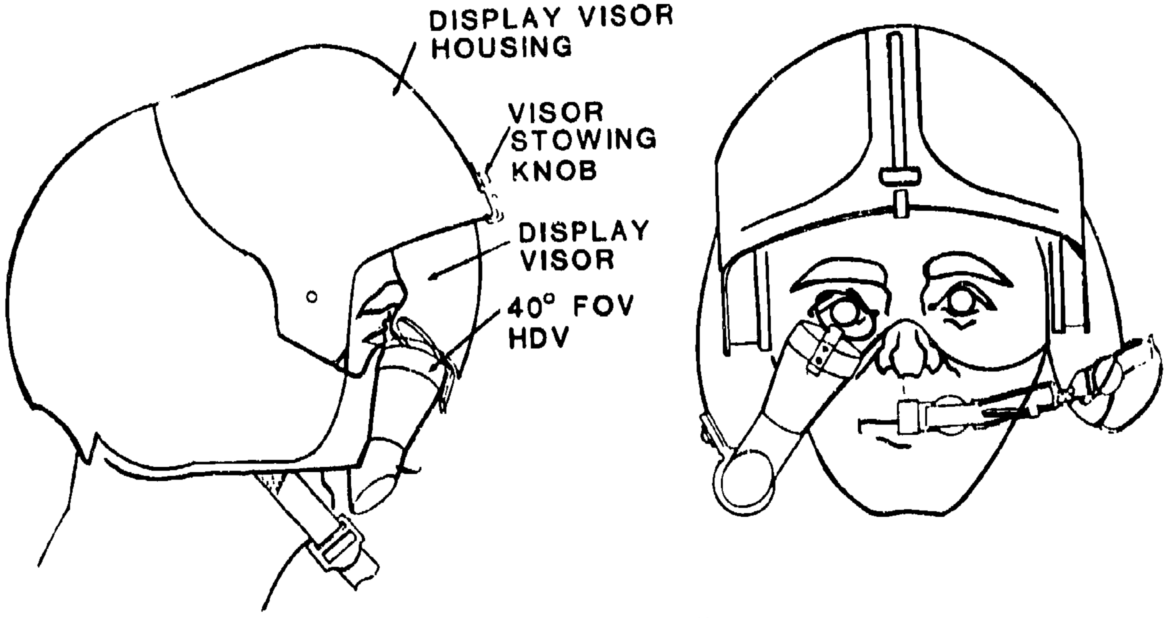

Figure 2. Honeywell Helmet Display Unit.

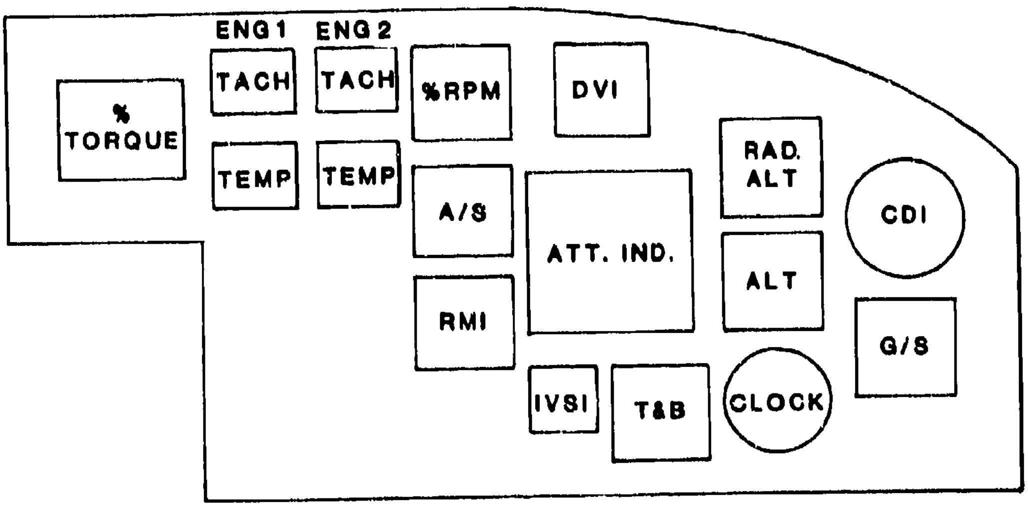

Figure 3. SH-2F Instrument Panel.

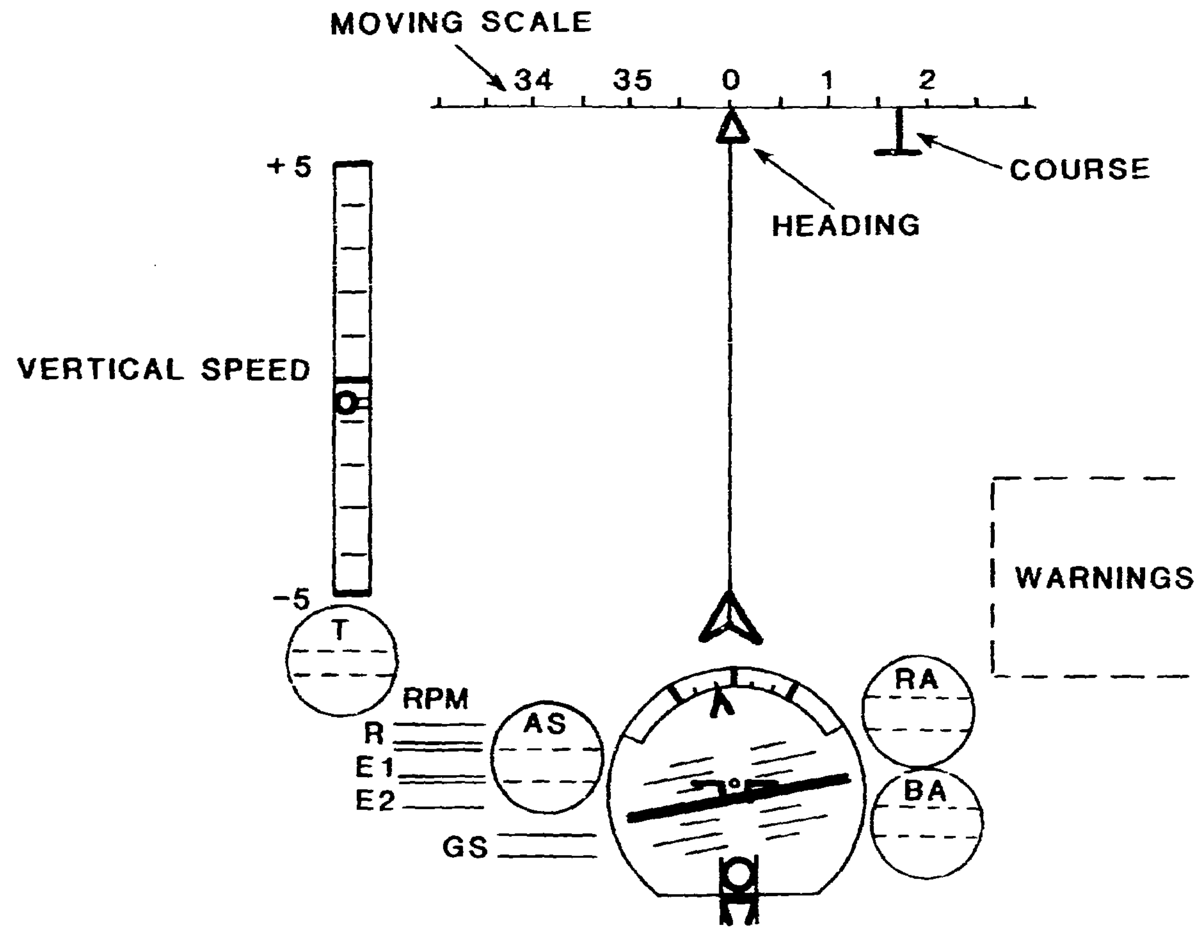

Figure 4. Basic "Maximal" HMD Format.

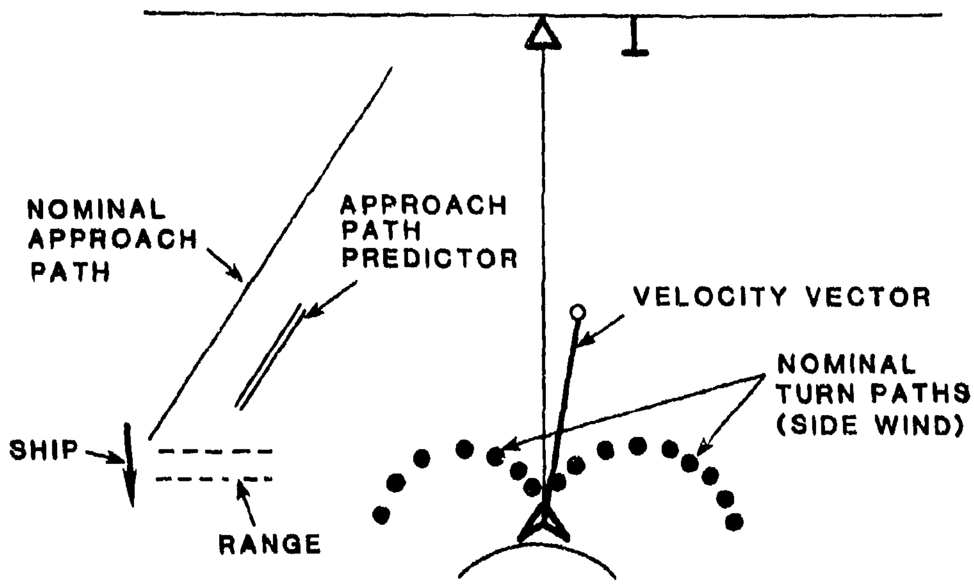

Figure 5. Localizer Acquisition Mode.

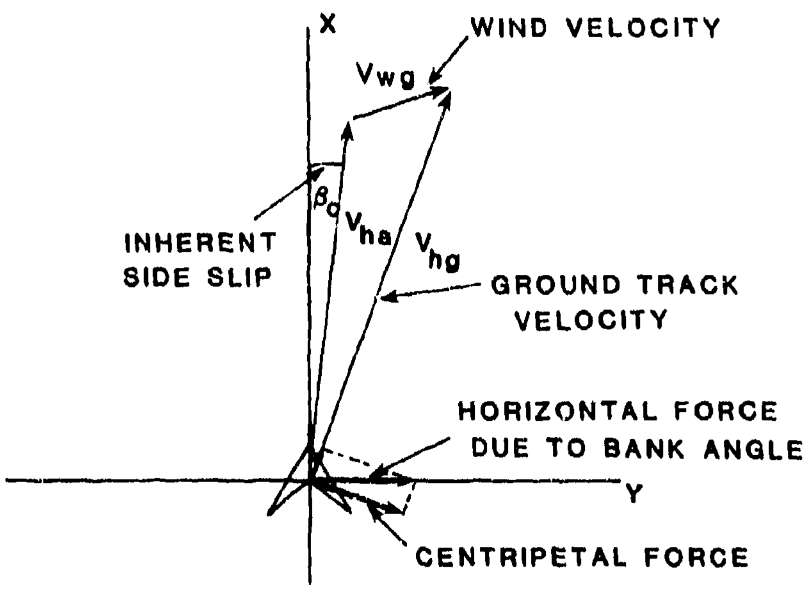

Figure 6. Vectors in Level Turning Flight.

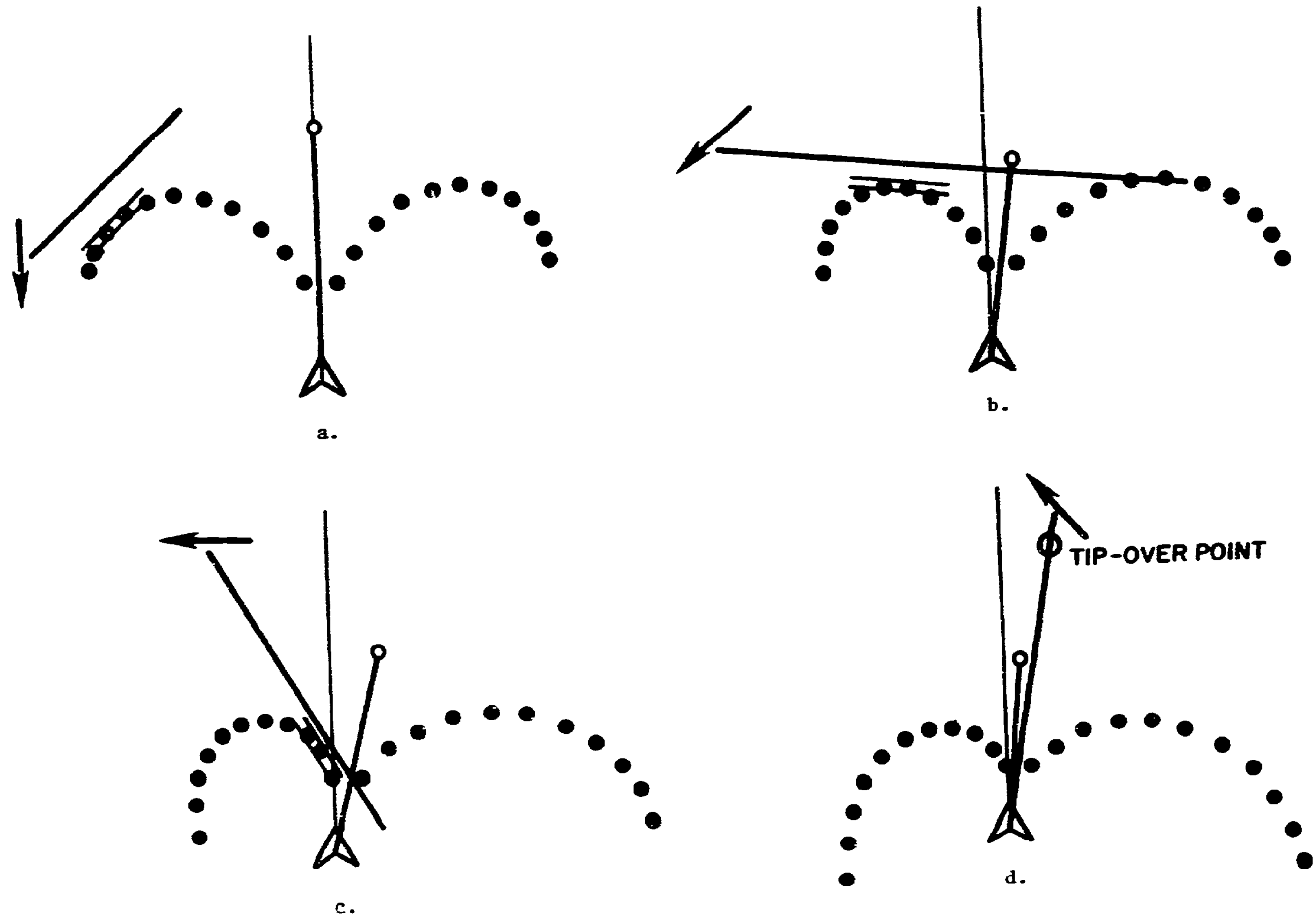

Figure 7. Left and Right Nominal Turn Ground Tracks Displayed While Turning Onto Localizer Under High Wind Condition.

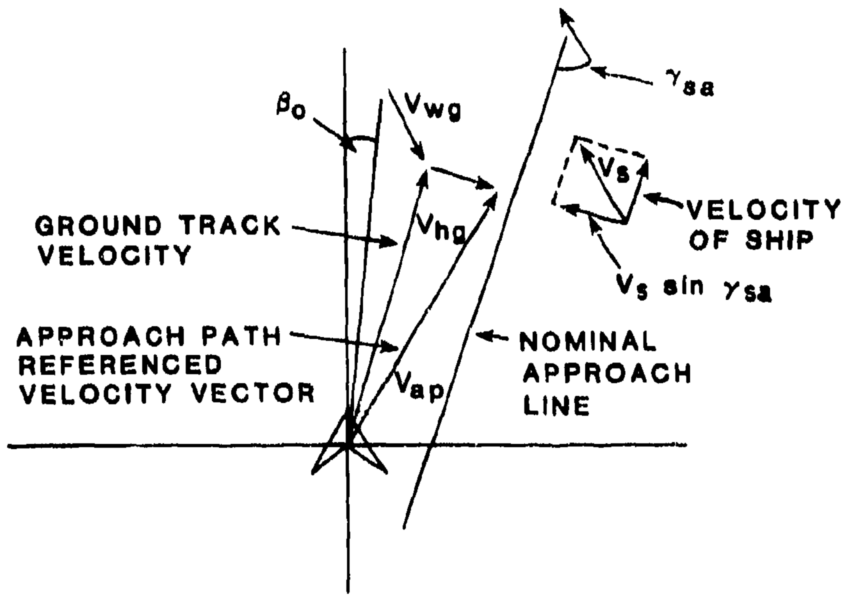

Figure 8. Velocity Vectors During Approach.

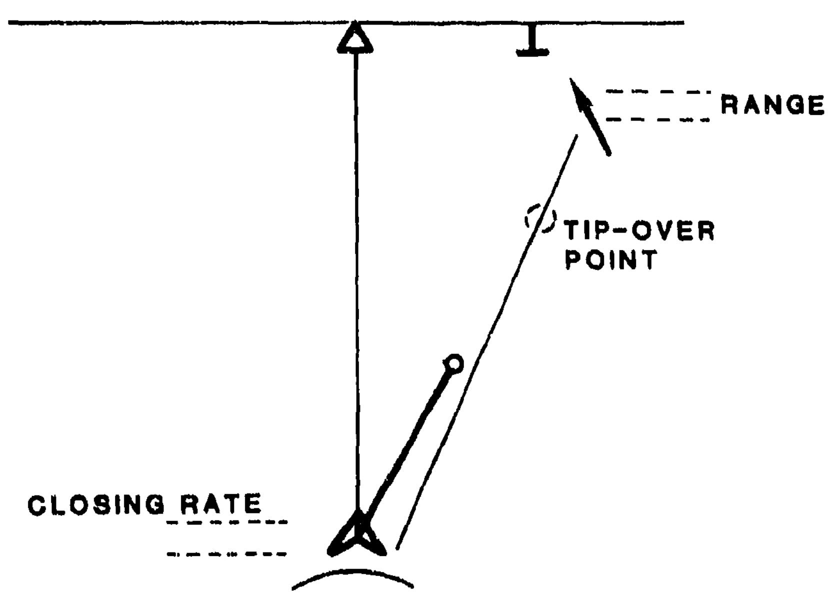

Figure 9. Approach Mode.

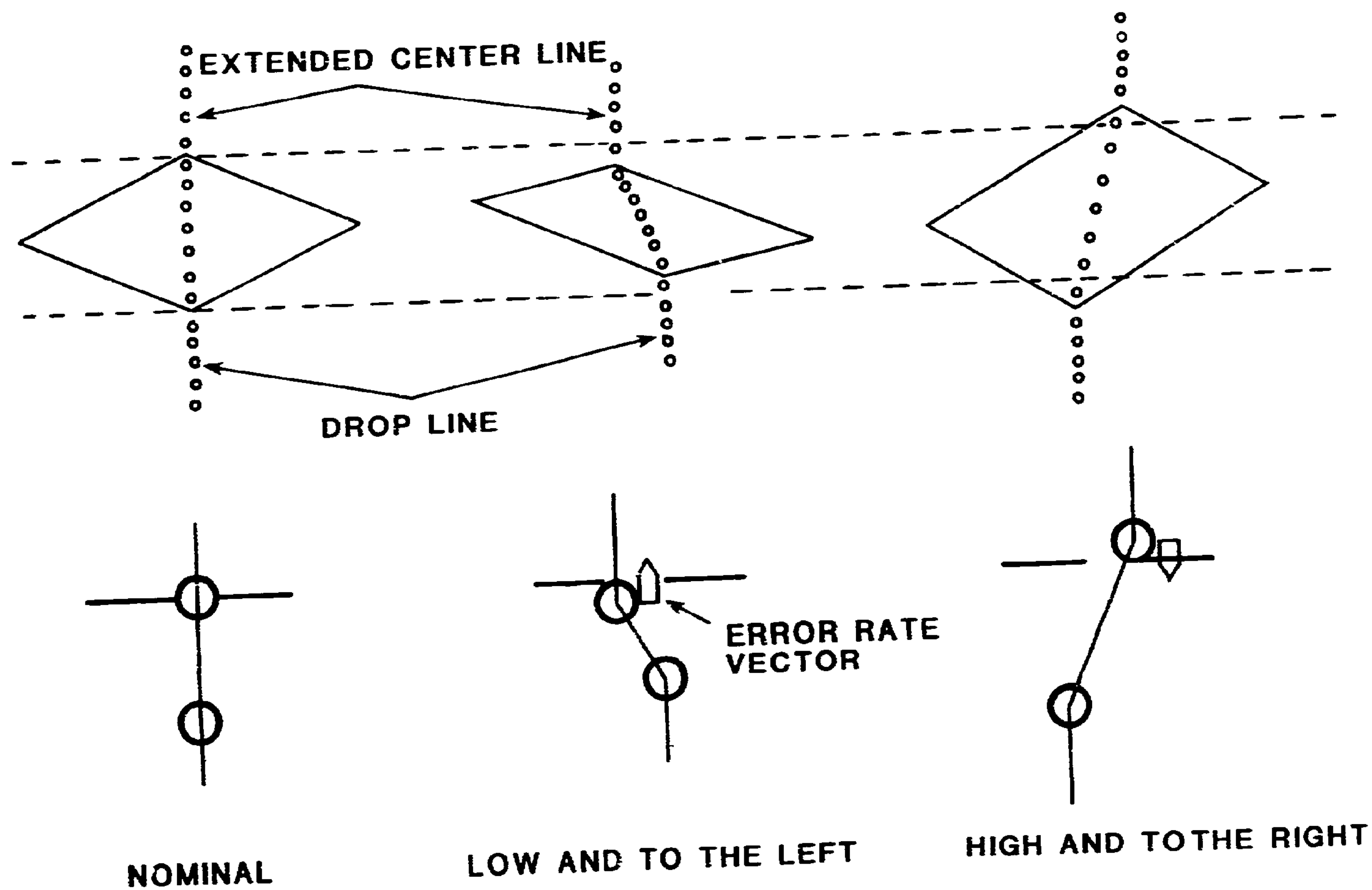

Figure 10. Vertical Symbology.

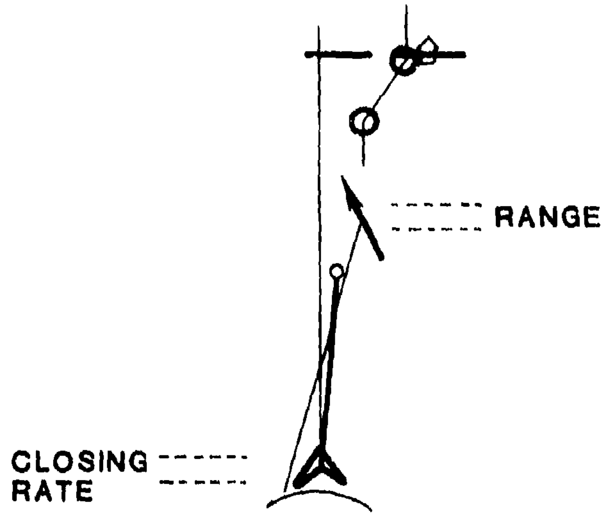

Figure 11. Approach Mode Near and After Tip-Over.

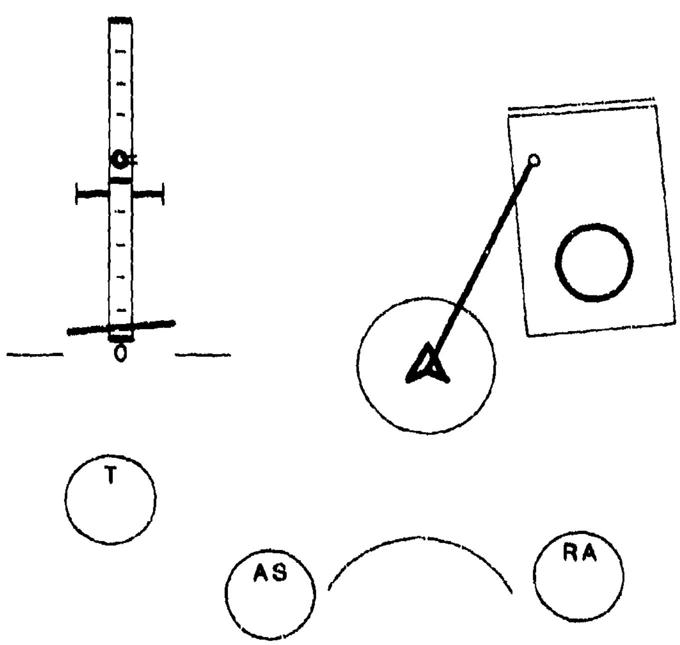

Figure 12. Hover Mode.

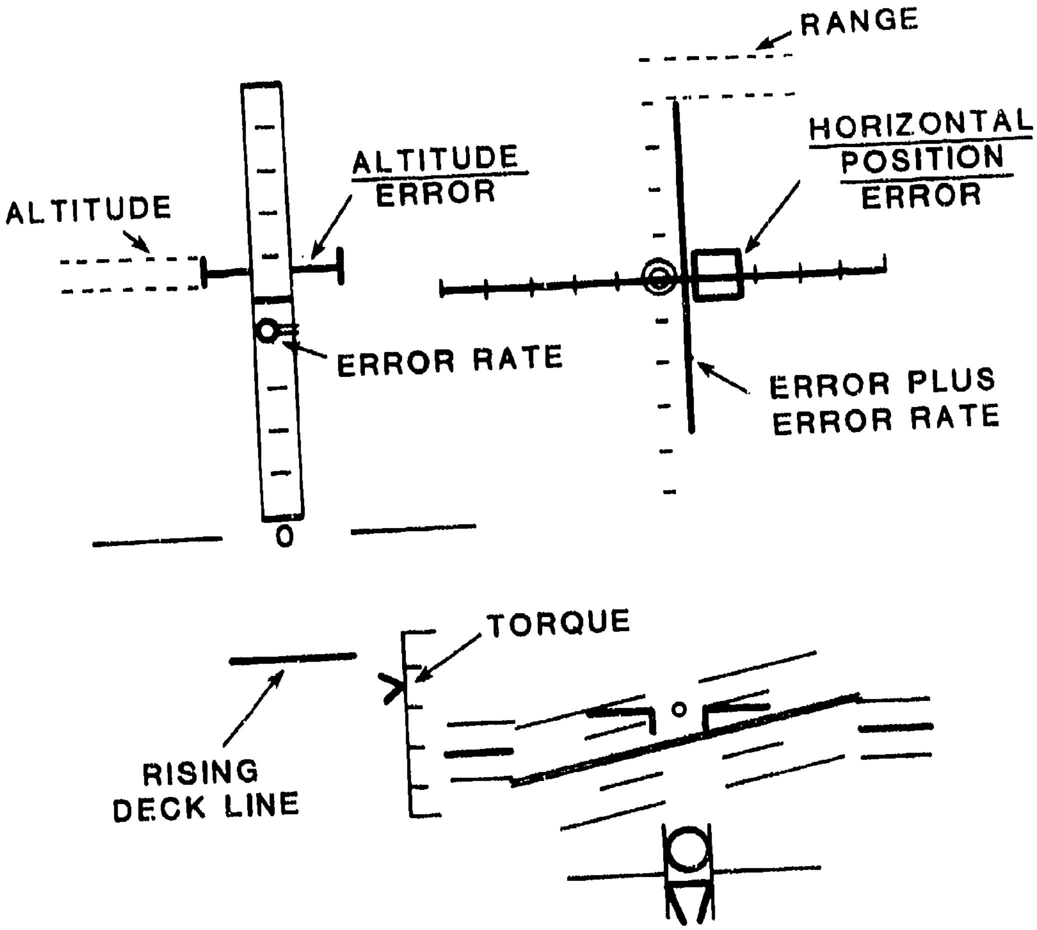

Figure 13. Minimal Display.

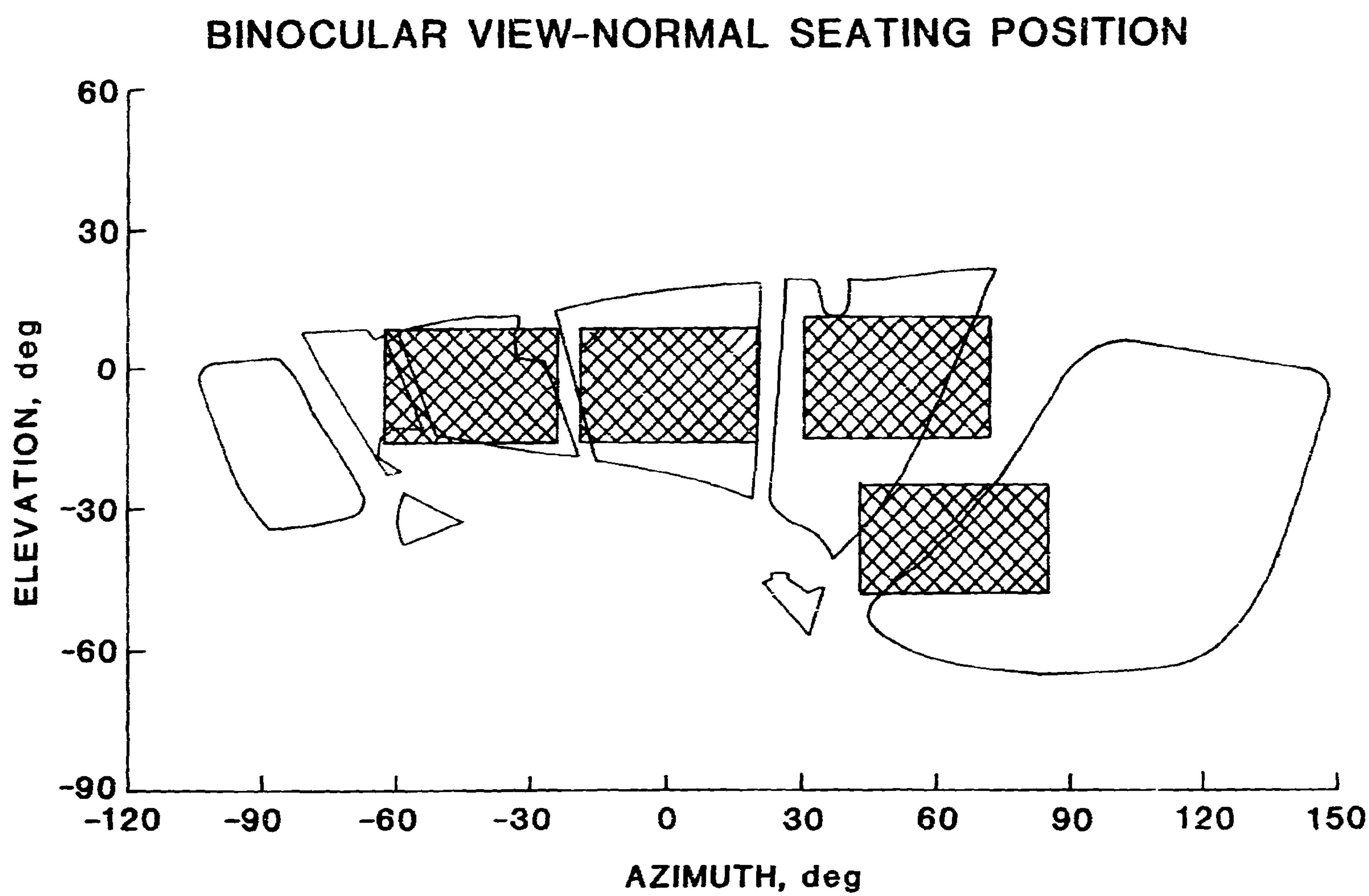

Figure 14. Actual and Simulator Field-of-View From Right Seat of an SH-2F.